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(54) **MICROWAVE FILTER AND MICROWAVE BRAZING SYSTEM THEREOF**

(75) Inventors: **Kin Yong Lim**, Singapore (SG); **Garimella Balaji Rao**, Singapore (SG)

(73) Assignee: **Turbine Overhaul Services Pte Ltd**, Jurong Town (SG)

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B01J 19/12	(2006.01)
H05B 6/80	(2006.01)
B23K 1/00	(2006.01)
B23K 1/005	(2006.01)

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(58) **Field of Classification Search**
CPC B23K 1/0018; B23K 1/005; H05B 6/80
USPC .... 219/679, 744, 685, 686, 738; 333/81 B; 156/345.42; 118/723 R; 204/298.38; 34/287
See application file for complete search history.

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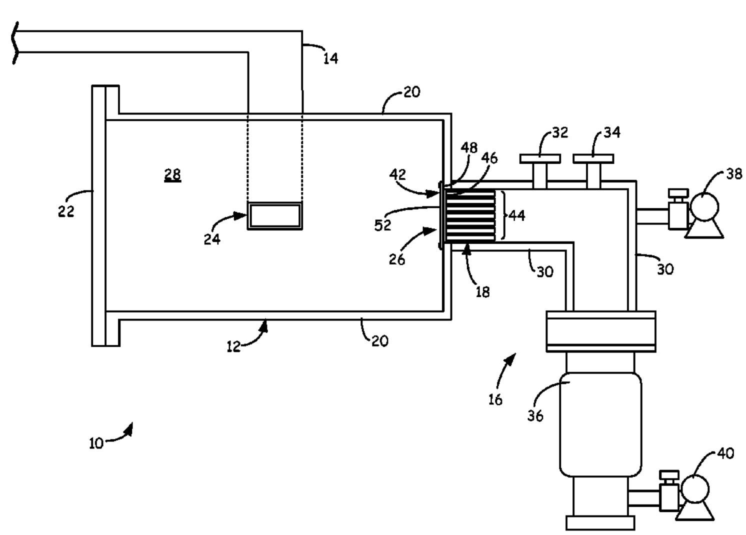
Primary Examiner — Quang Van
(74) *Attorney, Agent, or Firm* — Kinney & Lange, P.A.

(57) **ABSTRACT**

A microwave filter for use with a microwave brazing system having a brazing chamber, a vacuum line, and a pressure gauge located proximate the vacuum line. The microwave filter includes a baffle plate configured to be mounted in an opening between the brazing chamber and the pressure gauge, and a plurality of hollow pipes configured to substantially prevent the transmission of microwaves from the brazing chamber to the pressure gauge, and further configured to allow gas to flow between the brazing chamber and the vacuum line.

10 Claims, 3 Drawing Sheets



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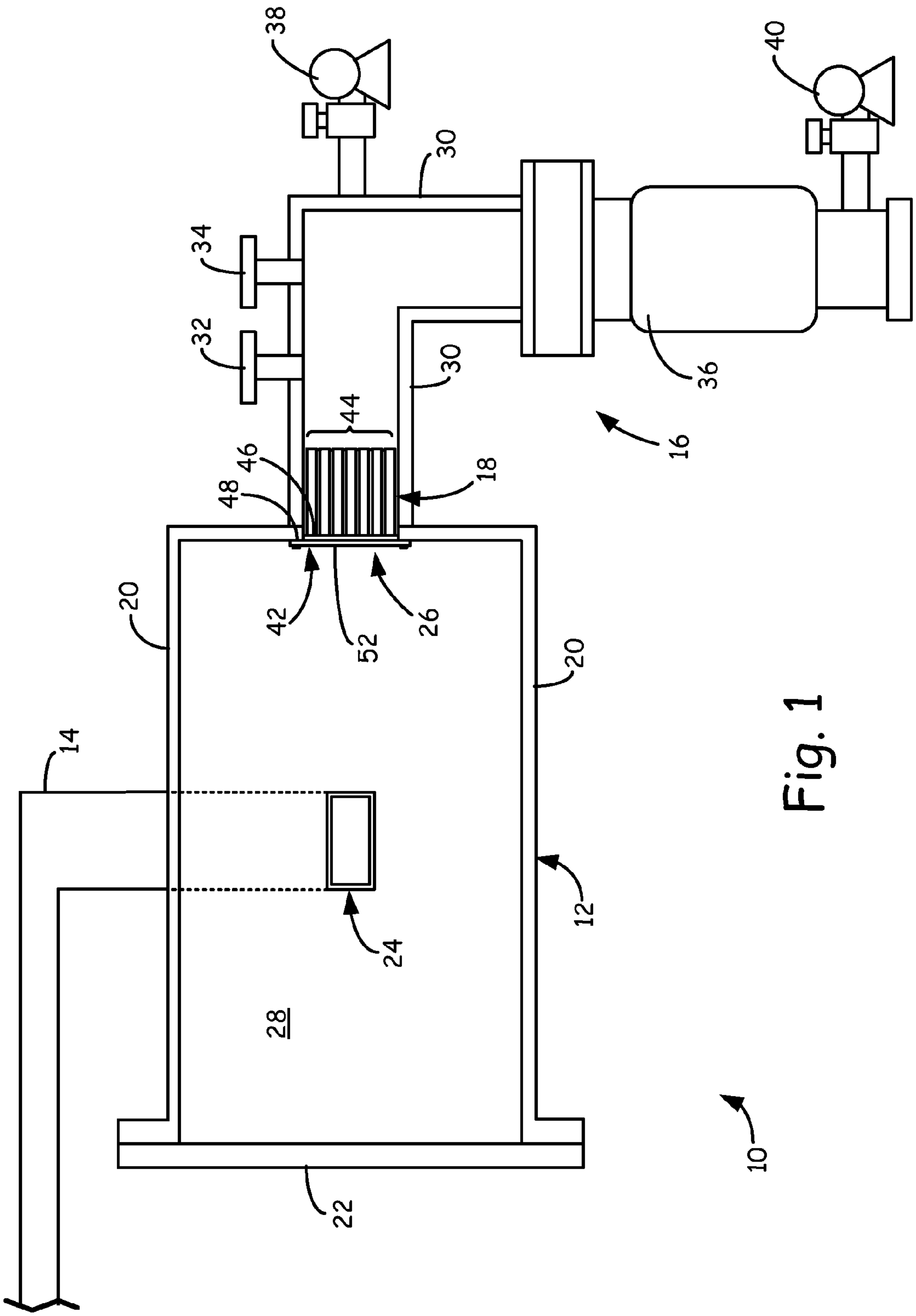


Fig. 1

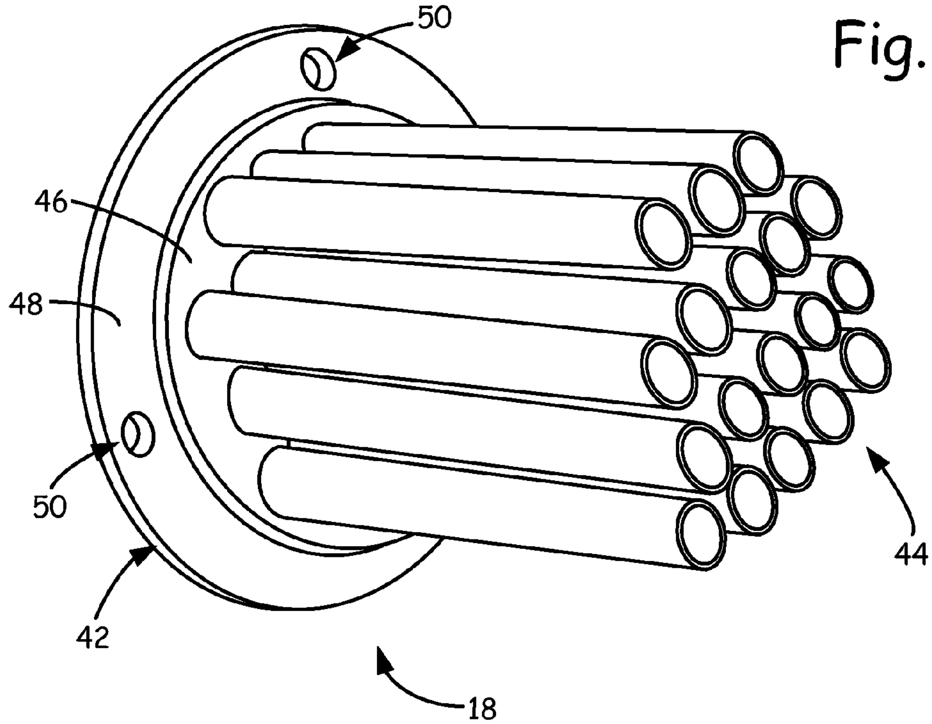


Fig. 2

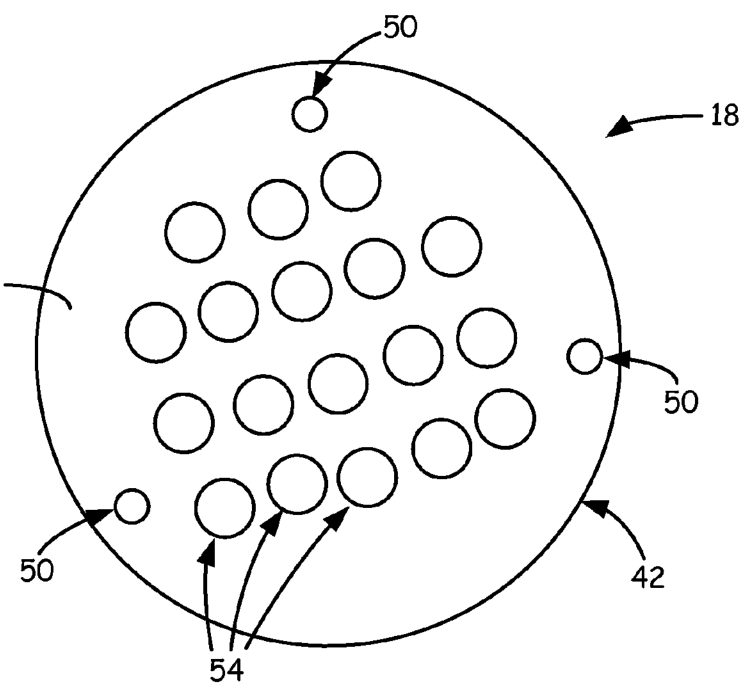
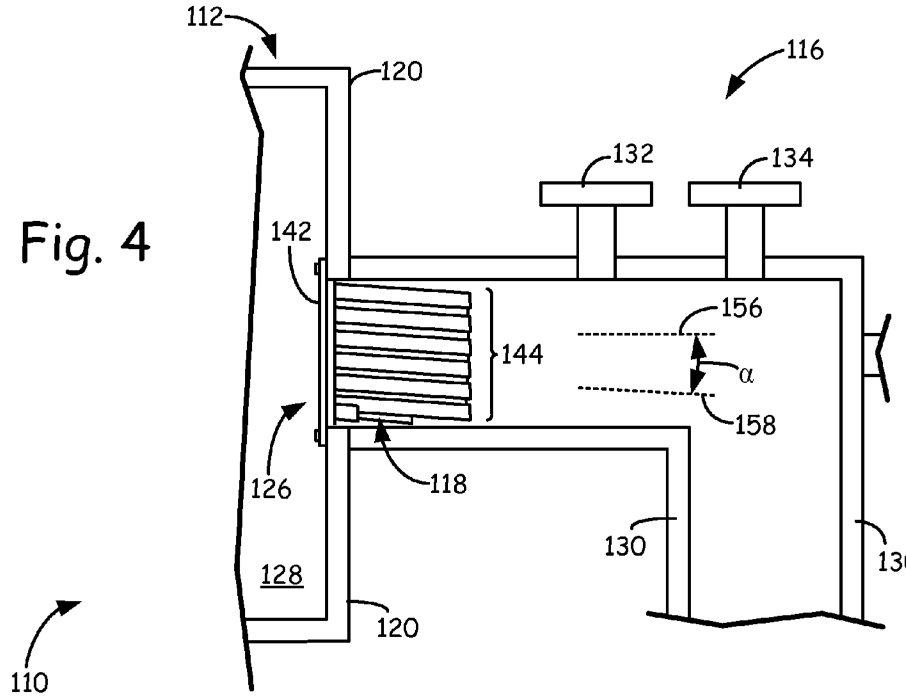


Fig. 3



112
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120
132
134
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144
α
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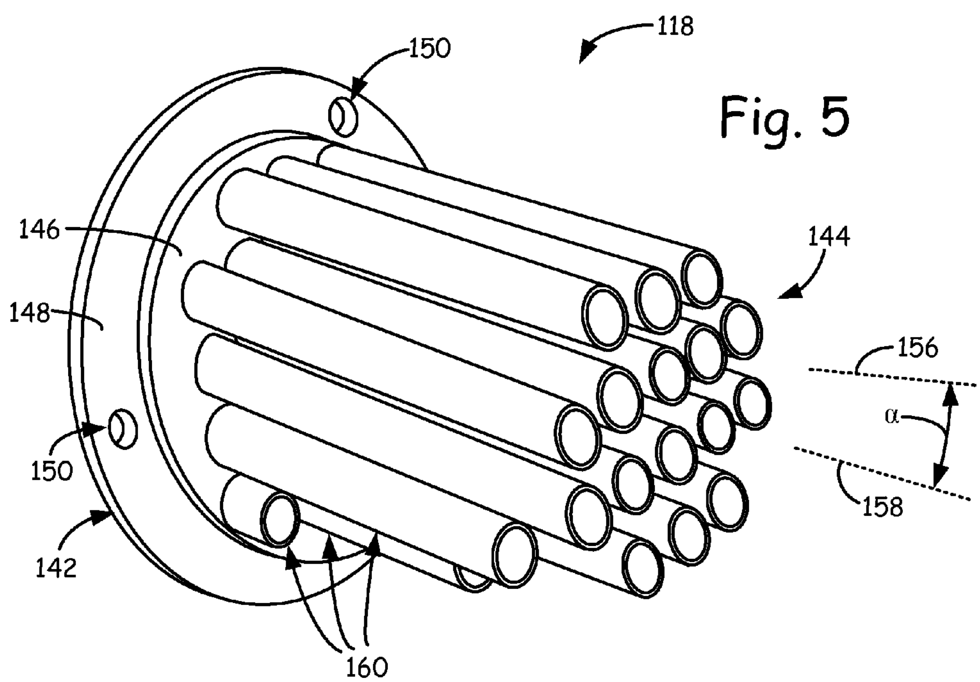
126
118
130
130
128
120
110

Fig. 4



118
150
146
144
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142
160

Fig. 5

MICROWAVE FILTER AND MICROWAVE BRAZING SYSTEM THEREOF

CROSS-REFERENCE TO RELATED APPLICATION(S)

This application is a divisional application of U.S. application Ser. No. 11/999,961, filed on Dec. 7, 2007, and which claims priority to Singapore Patent Application No. 200717210-9, filed on Oct. 26, 2007, and entitled "Microwave Filter and Microwave Brazing System Thereof", the disclosure of which is incorporated by reference in its entirety.

BACKGROUND

The present invention relates to systems for repairing metal components, such as gas turbine engine components. In particular, the present invention relates to microwave brazing systems for repairing metal components.

Superalloys of nickel, cobalt, and iron, single crystal or equiaxed, are typically employed in gas turbine engine components due to the high mechanical strengths and creep resistances obtained with such alloys. Because gas turbine engine components are exposed to extreme temperatures and pressures, high mechanical strengths and creep resistances are required to preserve the integrity of the engine over the course of operation. However, over time, exposed portions of the components are subject to wear, cracking, and other degradations, which can lead to decreases in operational efficiencies.

Due to economic factors, it is common practice in the aerospace industry to restore turbine engine components rather than replace them. Such restorations desirably restore damaged regions of the engine components to their original dimensions. Engine cracks are typically repaired with brazing operations, which subject the single crystal alloys of the engine components to high temperatures (e.g., 1200° C./2200° F.) for extended durations (e.g., 10 hours). Exposure to the high temperatures for the extended durations, however, reduces the low-temperature (e.g., 815° C.-870° C./1500° F.-1600° F.) creep resistances of the single crystal alloys. This is believed to be due to coarsening of the gamma prime (γ') phases of the single crystal alloys, which is measurable by increases in the average particle sizes of the γ' phases. The reduction of the low-temperature creep resistances can cause the alloy structures of the engine components to creep under the applied temperatures and pressures during operation, thereby also reducing operational efficiencies.

One technique for restoring engine components that substantially preserves the low-temperature creep resistances of single crystal alloys involves microwave brazing. Microwave brazing uses microwave-wavelength radiation to melt and fuse a brazing alloy with the base material of the damaged engine component. The microwave brazing process reduces the duration and temperature that the base material is exposed to, thereby substantially preserving the low-temperature creep resistances of the single crystal alloys. A microwave brazing process is typically performed in a brazing chamber under vacuum to provide a uniform braze and to reduce the risk of generating glow discharges and plasmas. However, pressure gauges used to measure the reduced pressure within the brazing chamber are sensitive to the microwaves used in the microwave brazing process. This may provide erroneous pressure measurements during the microwave brazing process, thereby reducing the ability to obtain the desired

vacuum environment. As such, there is a need for a system capable of providing accurate pressure measurements during microwave brazing processes.

SUMMARY

The present invention relates to a microwave filter for use with a microwave brazing system having a brazing chamber, a vacuum line, and a pressure gauge located proximate the vacuum line. The microwave filter includes a baffle plate configured to be mounted in an opening between the brazing chamber and the pressure gauge, where the baffle plate includes a first face, a second face that opposes the first face, and a plurality of openings through the first face and the second face. The microwave filter further includes a plurality of hollow pipes extending from the second face of the baffle plate at the openings, where the plurality of hollow pipes are configured to substantially prevent the transmission of microwaves from the brazing chamber to the pressure gauge, and are further configured to allow gas to flow between the brazing chamber and the vacuum line.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a side schematic illustration of a microwave brazing system.

FIG. **2** is a rear perspective view of a microwave filter of the microwave brazing system.

FIG. **3** is a front view of the microwave filter of the microwave brazing system.

FIG. **4** is an expanded side schematic illustration of a portion of an alternative microwave brazing system.

FIG. **5** is a rear perspective view of a microwave filter of the alternative microwave brazing system.

DETAILED DESCRIPTION

FIG. **1** is a schematic illustration of system **10**, which is a microwave brazing system for repairing metal components (e.g., gas turbine engine blades and vanes) with the use of microwave-wavelength radiation (referred to herein as "microwaves") provided from a microwave generator (not shown). System **10** includes brazing chamber **12**, waveguide **14**, vacuum line **16**, and microwave filter **18**, where microwave filter **18** is configured to substantially prevent microwaves from entering vacuum line **16** during a microwave brazing process.

Brazing chamber **12** is the portion of system **10** that retains one or more metal components (not shown) during a microwave brazing process, and includes chamber wall **20** and door **22**. Chamber wall **20** is a metallic casing (e.g., steel casing) that provides an enclosed environment for the microwaves during the microwave brazing process, and includes waveguide port **24** and vacuum entrance **26**. Waveguide port **24** is a first opening through chamber wall **20** that provides access to waveguide **14** for receiving the generated microwaves from the microwave generator. Vacuum entrance **26** is a second opening in chamber wall **20** that provides access to vacuum line **16**, and, in the embodiment shown in FIG. **1**, is the location where microwave filter **18** is secured. Door **22** is a chamber door that may be hingedly connected to chamber wall **20**, where chamber wall **20** and door **22** define interior region **28**. Interior region **28** is the volume within chamber wall **20** and door **22** where the metal component is placed during the microwave brazing process. Brazing chamber **12** may also include additional components (not shown), such as viewing windows and heat exchangers to further assist the microwave brazing process.

Waveguide **14** is a waveguide that interconnects brazing chamber **12** (at waveguide port **24**) and the microwave generator. While illustrated with a rectangular geometry, waveguide **14** may alternatively exhibit different geometries (e.g., rectangular and circular geometries). Waveguide **14** allows the microwave generator to provide the microwaves to brazing chamber **12** for repairing the metal components with the microwave brazing process. Examples of suitable microwave generators for use with system **12** include systems configured to generate microwaves having frequencies of about 2.45 gigahertz (e.g., magnetron microwave generators).

Vacuum line **16** is a purge line for removing gases from brazing chamber **12** and includes conduit **30**, pressure gauges **32** and **34**, diffusion pump **36**, and mechanical pumps **38** and **40**. Conduit **30** is a conduit (i.e., rigid or flexible) having a first end secured to chamber wall **20** at vacuum entrance **30**, and a second end secured to diffusion pump **36** with a gate valve. Pressure gauges **32** and **34** are gauges (e.g., pirani and cold cathode gauges) secured to conduit **30**, and are configured to measure the pressure within conduit **30**. In alternative embodiments, vacuum line **16** may include a different number of pressure gauges such that system **10** includes at least one pressure gauge to measure the pressure within vacuum line **16**. Diffusion pump **36** and mechanical pumps **38** and **40** are pumps configured to purge gases from interior region **28** of brazing chamber **12** via conduit **30**. Diffusion pump **36** and mechanical pumps **38** and **40** are desirably in signal communication with pressure gauges **32** and **34** via one or more process control loops (not shown), which allows pressure gauges **32** and **34** to control diffusion pump **36** and mechanical pumps **38** and **40** based on the measured pressure within conduit **30**.

Microwave filter **18** is a filter disposed through vacuum entrance **26**, and is configured to substantially prevent microwaves located in interior region **28** from entering conduit region **42**. This prevents the microwaves used in the microwave brazing process from interfering with pressure measurements of pressure gauges **32** and **34**. Microwave filter **18** includes baffle plate **42** and hollow pipes **44**, where baffle plate **42** is the portion of microwave filter **18** secured to chamber wall **20**, and hollow pipes **44** are supported by baffle plate **42** in a cantilevered manner within conduit **30**. As discussed below, hollow pipes **44** are configured to allow gases to flow from interior region **28** of brazing chamber **12** to conduit **30**. As such, the pressure within conduit **30** is the same as the pressure of interior region **28**. This allows pressure gauges **32** and **34** to effectively measure the pressure within interior region **28** while being isolated from the microwaves located within interior region **28**. While microwave filter **18** is disposed at vacuum entrance **26** in the embodiment shown in FIG. **1**, microwave filter **18** may alternatively be secured to different components of system **10** so long as microwave filter **18** is disposed between interior region **28** and pressure gauges **32** and **34**.

During a brazing process, door **22** is opened and a metal component containing a brazing alloy (not shown) is inserted within interior region **28**. Examples of suitable metal components, brazing alloys, and techniques for applying the brazing alloys for a microwave brazing process are discussed in Garimella, U.S. Patent Application Publication No. 2006/0071053, which is hereby incorporated in full by reference. Door **22** is then closed, and the gases (e.g., air) are then pumped from interior region **28** of brazing chamber **12** with diffusion pump **36** and mechanical pumps **38** and **40**. Pressure gauges **32** and **34** measure the pressure within conduit **30** and identify when a desired pressure is obtained. As discussed above, performing the microwave brazing process under reduced pressure (e.g., vacuum) provides a uniform braze to the metal component and reduces the risk of generating glow discharges and plasmas. Examples of suitable pressures for performing the microwave brazing process include about 13 millipascals (about 10^{-4} Torr) or less, with more particularly suitable pressures including about 1.3 millipascals (about 10^{-5} Torr) or less.

After the desired reduced pressure is obtained, pressure gauges **32** and **34** continue to measure the pressure within conduit **30**, which corresponds to the pressure within interior region **28**. If the pressure within interior region **28** and conduit **30** changes due to the microwave brazing process, pressure gauges **32** and **34** desirably adjust the pumping intensities of diffusion pump **36** and/or mechanical pumps **38** and **40** to stabilize the pressure at the desired reduced pressure.

The microwave generator then emits microwaves to interior region **28** of brazing chamber **12** via waveguide **14** and waveguide port **24** to initiate the microwave brazing process. The microwaves heat the metal component and the brazing alloy as discussed in Garimella, U.S. Patent Application Publication No. 2006/0071053, thereby allowing the brazing alloy to interdiffuse into the base material of the metal component. Upon entrance to brazing chamber **12**, the microwaves bounce off metallic obstructions, such as the metal component, the brazing alloy, chamber wall **20**, and door **22**. As such, portions of the reflected microwaves attempt to enter conduit **30** via vacuum entrance **26**. However, as discussed below, microwave filter **18** substantially prevents the microwaves from entering conduit **30**. As used herein, the term "substantially prevents" with respect to the flux of microwaves across microwave filter **18** refers to less than about 1% of the microwaves penetrating through microwave filter **18**. Such levels of microwave penetration do not provide observable interferences of pressure measurements with pressure gauges **32** and **34**.

Substantially preventing the microwaves entering conduit **30** correspondingly prevents the microwaves from interfering with pressure gauges **32** and **34**. If substantial concentrations of microwaves were otherwise allowed to contact pressure gauges, such as pirani gauges and cold cathode gauges, the microwaves may disrupt the pressure measurements, thereby providing erroneous signals to the process control loops controlling diffusion pump **36** and mechanical pumps **38** and **40**. For example, a pirani gauge typically incorporates a metallic wire that is heated with an electrical current and is cooled by the gas in a chamber, where the rate of cooling is dependent on the concentration of the gas in the chamber. If the metallic wire is exposed to the microwaves, the microwaves may heat the metallic wire, thereby providing a false temperature reading indicating that the pressure is lower than the actual pressure within conduit **30**.

Similarly, a cold cathode gauge measures electrical ions produced when the gas in a chamber is bombarded with electrons, where the number of electrical ions produced is dependent on the concentration of the gas in the chamber. Microwave interference with the cold cathode gauge may result in false identification of electrical ions, which indicates that the pressure is greater than the actual pressure within conduit **30**. Accordingly, microwave filter **18** allows pressure gauges **32** and **34** to effectively measure the pressure within brazing chamber **12**, while also substantially preventing the microwaves from entering vacuum line **16**, thereby preventing interference with pressure gauges **32** and **34**. As a result, the pressure within brazing chamber **12** may be accurately measured during the microwave brazing process.

FIG. **2** is a rear perspective view of microwave filter **18**, further illustrating baffle plate **42** and hollow pipes **44**. As shown, baffle plate **42** includes inner rear face **46**, outer rear face **48**, and bolt holes **50**, where inner rear face **46** is the portion of baffle plate **42** that faces conduit **30** (shown in FIG. **1**). Outer rear face **48** is the portion of baffle plate **42** that is disposed against chamber wall **20** (shown in FIG. **1**) for securing microwave filter **18** to chamber wall **20** via bolts (not shown) extending through bolt holes **50**.

Hollow pipes **44** are a plurality of elongated, hollow pipes extending from inner rear face **46**. As discussed above, hollow pipes **46** allow the passage of gases from brazing chamber **12** (shown in FIG. **1**) to conduit **30**, but substantially prevent the transmission of the microwaves. As the microwaves from brazing chamber **12** enter hollow pipes **44**, the microwaves continuously reflect off the inner surfaces of hollow pipes **44**. For a given microwave, each reflection converts a portion of the energy of the microwave into heat. Thus, the successive reflections within hollow pipes **44** continuously reduce the energy levels of the microwaves until the microwaves do not have enough remaining energy to further reflect. Accordingly, each of hollow pipes **44** desirably has a length-to-diameter ratio that is suitable for substantially preventing the transmission of microwaves, and that allows a suitable gas flow for balancing the pressures between brazing chamber **12** and conduit **30**.

As used herein with respect to a pipe of a microwave filter (e.g., hollow pipes **44** of microwave filter **18**), the term "diameter" refers to the average inner diameter of the pipe, where the average inner diameter is taken along the length of the pipe. The actual dimensions of hollow pipes **44** may vary depending on multiple factors, such as the size of conduit **30** and the number of hollow pipes **44**. In the embodiment shown in FIG. **2**, hollow pipes **44** have circular cross sections. In alternative embodiments, hollow pipes **44** may have cross sections with different geometric dimensions (e.g., oval and rectangular).

Examples of suitable length-to-diameter ratios for each of hollow pipes **44** include ratios of at least about 6-to-1, with particularly suitable length-to-diameter ratios including ratios of at least about 10-to-1, and with even more particularly suitable length-to-diameter ratios including ratios of at least about 20-to-1. Examples of suitable lengths for each of hollow pipes **44** from inner rear face **46** range from about 5 centimeters to about 50 centimeters, with particularly suitable lengths ranging from about 10 centimeters to about 20 centimeters. While microwave filter **18** is shown in FIG. **2** with 18 hollow pipes **44**, microwave filter **18** may alternatively include greater and fewer numbers of hollow pipes **44** depending on the dimensions of hollow pipes **44** and the cross-sectional area of conduit **30**. Examples of suitable numbers of hollow pipes **44** range from 5 pipes to 50 pipes, with particularly suitable numbers of hollow pipes **44** ranging from 10 pipes to 30 pipes, and with even more particularly suitable numbers of hollow pipes **44** ranging from 15 pipes to 25 pipes.

FIG. **3** is a front view of microwave filter **18**, where baffle plate **42** further includes front face **52** and pipe openings **54**. Front face **52** is the portion of microwave filter **18** that faces interior region **28** of brazing chamber **12** (shown in FIG. **1**), and is the opposing face of inner and outer rear faces **46** and **48** (shown in FIG. **2**). Pipe openings **54** are holes within front face **52** that substantially align with the diameters of hollow pipes **44** (shown in FIG. **2**). This allows the gases to flow through microwave filter **18** to balance the pressures between brazing chamber **12** and conduit **30** (shown in FIG. **1**). As discussed above, this allows pressure gauges **32** and **34** to effectively measure the pressure of interior region **28** while being isolated from the microwaves located within interior region **28**.

FIG. **4** is an expanded side schematic illustration of a portion of system **110**, which is an alternative microwave brazing system to system **10** (shown in FIG. **1**) and functions in the same manner for performing microwave brazing processes, where the corresponding reference labels are increased by "100". As shown in FIG. **4**, microwave filter **118** includes baffle plate **142** and hollow pipes **144**, where hollow pipes **144** extend at an angle that directs hollow pipes **144** away from pressure gauges **132** and **134**. In this embodiment, baffle plate **142** is orthogonal to longitudinal axis **156**, which is generally parallel to the portion of conduit **130** that microwave filter **118** is disposed in. In comparison, hollow pipes **144** extend along offset axis **158**, where offset axis **158** is disposed at an angle α to longitudinal axis **156**. Thus, hollow pipes **144** extend away from pressure gauges **132** and **134**. Accordingly, any transient microwaves that transmit through microwave filter **118** are directed away from pressure gauges **132** and **134**, thereby further reducing the risk of microwaves interfering with pressure gauges **132** and **134**. Examples of suitable angles α for offset axis **158** relative to longitudinal axis **156** range from greater than zero degrees to less than about 30 degrees, with particularly suitable angles α ranging from about 5 degrees to about 15 degrees.

FIG. **5** is a rear perspective view of microwave filter **118**, further illustrating the arrangement of hollow pipes **144**. As shown, a portion of hollow pipes **144** (referred to as hollow pipes **160**) are shorter than the majority of hollow pipes **144**. Because hollow pipes **144** are oriented at angle α relative to longitudinal axis **156**, if each of hollow pipes **144** had a length-to-diameter ratio corresponding to the above-discussed suitable length-to-diameter ratios, a portion of hollow pipes **144** would not fit within conduit **30**. As such, hollow pipes **160** have lower length-to-diameter ratios to allow microwave filter **118** to fit within conduit **30**. While the lower length-to-diameter ratios may not entirely prevent transmission of the microwaves through hollow pipes **160**, the energy levels of the microwaves are partially reduced to reduce the affect of such microwaves on pressure gauges **132** and **134**. In an alternative embodiment, hollow pipes **160** may be omitted and baffle plate **142** may be sealed at the locations of hollow pipes **160**, thereby preventing the transmission of microwaves at such locations.

Although the present invention has been described with reference to preferred embodiments, workers skilled in the art will recognize that changes may be made in form and detail without departing from the spirit and scope of the invention.

The invention claimed is:

1. A microwave brazing system comprising:

a brazing chamber having a chamber wall;

a first opening disposed through the chamber wall and configured to relay microwaves from a microwave generator;

a second opening disposed through the chamber wall;

a conduit connected to the brazing chamber at the second opening;

at least one pressure gauge secured to the conduit, and configured to measure pressure within the conduit; and

a microwave filter disposed between the brazing chamber and the at least one pressure gauge, the microwave filter comprising a plurality of hollow pipes configured to substantially prevent the transmission of microwaves from the brazing chamber to the conduit, while allowing gas to flow between the brazing chamber and the conduit;

wherein the microwave filter further comprises a baffle plate secured to the chamber wall, wherein the plurality of hollow pipes are secured in a cantilevered manner from the baffle plate to extend into the conduit;

wherein the plurality of hollow pipes extend into the conduit along an offset axis, the offset axis disposed at a nonzero angle α relative to a longitudinal axis, the longitudinal axis orthogonal to an inner rear face of the baffle plate.

2. The microwave brazing system of claim **1**, wherein the plurality of hollow pipes are a first plurality of hollow pipes, and wherein the microwave filter further comprises a second plurality of hollow pipes having length-to-diameter ratios that are less than length-to-diameter ratios of the first plurality of hollow pipes.

3. The microwave brazing system of claim **1**, wherein the plurality of hollow pipes comprise a number of hollow pipes ranging from 5 pipes to 50 pipes.

4. The microwave brazing system of claim **1**, wherein the plurality of hollow pipes have length-to-diameter ratios of at least about 6-to-1.

5. The microwave brazing system of claim **1**, further comprising at least one pump connected to the conduit for reducing the pressure within the conduit.

6. The microwave brazing system of claim **1**, wherein the nonzero angle α directs the hollow pipes away from the at least one pressure gauge in the conduit.

7. The microwave brazing system of claim **6**, wherein the nonzero angle α is less than 30°.

8. The microwave brazing system of claim **7**, wherein the nonzero angle α is between 5° and 15°.

9. The microwave brazing system of claim **1**, wherein the nonzero angle α is less than 30°.

10. The microwave brazing system of claim **9**, wherein the nonzero angle α is between 5° and 15°.

* * * * *